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Visual stability during saccades is achieved through transient changes in perceptual space and time

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Abstract

To interact rapidly and effectively with our environment, our brain needs access to a dynamic neural representation – or *map* – of the spatial layout of the external world. One of the major challenges to constructing such a map is the frequent rapid movements of the eyes, which displace the images on our retinae, up to three times per second. Much neurophysiological research shows that just before saccades, the receptive fields of neurons in many visual areas are subject to large shifts, in the direction of the saccade (Duhamel, Colby, & Goldberg, 1992). While the neural mechanisms of this dynamic process are now well understood (Sommer & Wurtz, 2006), it is less clear how a shift in the direction of the saccade benefits perception.

We suggest that the purpose of the shifts in receptive fields is to prepare for the effects of saccades before they commence, and that the real work of stabilizing occurs when they relax back into their standard position during the actual saccade (Burr & Morrone, 2011, 2012; Cicchini, Binda, Burr, & Morrone, 2012). It is this relaxation that compensates for the saccadic displacement. The relaxation process is best described as a shift in both space and in time, and this can be well described by spatiotemporal receptive field that is slanted in space-time (see figure 9 from Cicchini, Binda, Burr, & Morrone, 2012).

We have accumulated a wealth of psychophysical evidence supporting the notion of the spatiotemporal shift. Perhaps the strongest evidence is the temporal lag that occurs during saccades, a clear signature of a spatiotemporal transformation. During saccades, visual flashes are perceived to be delayed by 100 ms compared with normal viewing (Binda, Cicchini, Burr, & Morrone, 2009), and it is this delay that creates the spatiotemporal tuning (as do motion perception mechanisms, on a different timescale; Burr, Ross, & Morrone, 1986). There is also strong temporal compression, so stimuli 100 ms long are perceived as 50 ms (Morrone, Ross, & Burr, 2005); we have developed a simple model that explains how the temporal compression results from a spatiotemporal shift (Cicchini & Morrone, 2012). Recently, neurophysiological studies find similar delays and compression in neurones of cortical area FEF (Joiner, Cavanaugh, & Wurtz, 2013). Finally, we have explicitly measured the spatiotemporal

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interaction field of stimuli flashed around the time of the saccade, and report a field like that shown in figure 9 of Cicchini, Binda, Burr, and Morrone (2012).

All up these studies show clear evidence for a spatiotemporal mechanism that creates transient spatiotopy at the time of saccades, allowing perceptual systems to momentarily bridge the transition between one fixation and another. This process cannot be understood as only a spatial transform, as it is inherently spatiotemporal, resulting in strong and measureable delays and compression of time.

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Keywords: Visual stability; Time; Spatiotemporal receptive fields; Spatiotopy

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